Clinical Medicine

Contact Lens Wear at Altitude: Subcontact Lens Bubble Formation

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A concern in the past regarding contact lens wear in aviation has been the fear of subcontact lens bubble formation. Previous reports have documented the occurrence of bubbles with hard (PMMA) lenses. Reported here are the results of contact lens bubble studies with soft hydrophilic and rigid gas-permeable lenses. Testing was accomplished in hypobaric chambers and onboard USAF transport aircraft. Hypobaric chamber flights were of three types: high-altitude flights up to 7,620 m (25,000 ft); explosive rapid decompressions from 2,438.4 m (8,000 ft) to 7,620 m (25,000 ft); and 4-h flights at 3,048 m (10,000 ft). Flights aboard transport aircraft typically had cabin pressures equivalent to 1,524-2,438.4 m (5,000-8,000 ft), and ranged in duration from 3 to 10 h. For subjects wearing rigid gas-permeable lenses, central bubbles were detected in 2 of 10 eyes and occurred at altitudes greater than 6,096 m (20,000 ft). With soft contact lenses, bubble formation was detected in approximately 24% (22 of 92 eyes) of the eyes tested, sometimes occurring at altitudes as low as 1,828.8 m (6,000 ft). Soft lens bubbles were always located at the limbus and were without sequela to vision or corneal epithelial integrity. Bubbles under the rigid lenses were primarily central, with potential adverse effects on vision and the corneal epithelium.

A CONCERN FOR contact lens wear in military aviation has been the fear of subcontact lens bubble formation and the potential for later physiologic and visual degradation. The quantity of a gas (i.e., nitrogen) that can remain dissolved in a solution—in this case, the precorneal tear film—is directly related to the absolute pressure. With increasing altitude, the atmospheric pressure drops off rapidly, reducing to one-half at 5,486.4 m (18,000 ft) and to one-quarter by 10,363 m (34,000 ft). Pressure differentials of this magnitude are encountered in military aviation, and therefore the concern of subcontact lens bubble formation would appear to be a valid one.

As early as 1944, Jaeckle (2) reported the incidence of subcontact lens bubble formation under scleral lenses at altitudes greater than 5,486.4 m (18,000 ft). Later, after many advances in contact lens fitting and design characteristics, Newsom *et al.* (3) reported bubble formation in 66% of the 16 polymethyl methacrylate (PMMA) corneal contact lens wearers they tested. Similar to Jaeckle's results, they reported bubble formation primarily at altitudes greater than 5,486.4 m (18,000 ft). They found that two subjects experienced blurred vision from formation of large bubbles under their contact lenses. They also found that the number and size of the bubbles varied with subject and altitude. Neither the PMMA lenses used by Newsom *et al.* nor the scleral lenses used by Jaeckle were permeable to gases such as oxygen or nitrogen.

Gas-permeable contact lens materials are available today in rigid or soft form. There are four general groups of gas-permeable rigid lenses: silicone and silicone-PMMA mixtures; cellulose acetate butyrate (CAB); and two new materials undergoing investigations, polystyrene and fluropolymers. These rigid lenses are fitted intrapalpebrally with a spherical back curve approximating the central corneal curvature. Lens centration is achieved by tear fluid forces, by the flattening of the peripheral cornea, and by the holding action of the superior eyelid. In addition to the property of gas permeability through the lens material, a significant amount is also pumped under the lens on each blink.

Soft (hydrophilic) lenses are made from a variety of different polymers, and most contain a large percentage of water (38%-79% by weight). The water contained in soft lenses is the primary conduit for gas permeability through the lens (4). Soft lenses are larger than the corneal diameter,

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and fit on the eye by bridging the peripheral cornea and limbus, and rest on the central cornea and sclera. Unlike rigid lenses, very little oxygen is pumped under the lens during blinking.

Reported here are the results from studies of subcontact lens bubble formation in subjects wearing rigid gas-permeable (silicone and silicone-PMMA mixture) and soft hydrophilic lenses. Accordingly, contact lens wear was evaluated as follows: simulated aircraft flights in hypobaric chambers ranging in altitude from 2,438.4 m (8,000 ft) to 7,620 m (25,000 ft); during rapid decompressions from 2,438.4 m (8,000 ft) to 7,620 m (25,000 ft); and onboard transport aircraft with cabin pressures equivalent to 1,524–2,438.4 m (5,000–8,000 ft).

MATERIALS AND METHODS

Rigid Gas-Permeable Lenses: Rigid gas-permeable lenses were evaluated in a hypobaric chamber with a 7,620 m (25,000ft)-equivalent atmospheric pressure, as shown in Fig. 1. Ascent rate was 1,524 m (5,000 ft)/min up to a level of 2,438.4 m (8,000 ft) and maintained for 30 min, then up to 7,620 m (25,000 ft) and maintained for 30 min. Descent rate was also 1,524 m (5,000 ft)/min, with 5-min stops every 1,524 m (5,000 ft).

Five subjects, from whom informed consent had been obtained, participated in this study. Each subject was tested in a minimum of two hypobaric chamber flights. Three of the five were successful wearers of rigid gas-permeable (silicone-PMMA mixture) lenses, and two were newly fitted with silicone rigid gas-permeable lenses. All were required to achieve successful daily wear before being tested in the hypobaric chambers.

Visual acuity measurements and slit lamp examinations were performed before, during, and after the chamber flights. The testing during the chamber flights was accomplished twice at 2,438.4 m (8,000 ft) and 7,620 m (25,000 ft), and at every 1,524 m (5,000 ft) during descent. Postflight slit-lamp examinations included the instillation of sodium fluorescein.

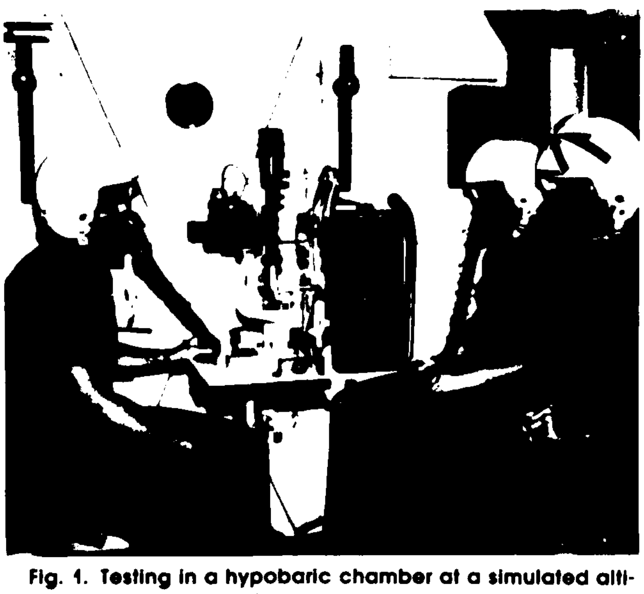

Fig. 1. Testing in a hypobaric chamber at a simulated altitude of 7,620 m (25,000 ft).

Fig. 2. Explosive rapid decompression in a hypobaric chamber from 2,438.4 m (8,000 ft) to 7,620 m (25,000 ft).

Soft Hydrophilic Lenses: A total of 46 subjects, wearing various soft lens polymers ranging from low to high water contents, were tested for bubble formation during a series of exposures to altitude. Testing was accomplished on simulated aircraft flights in hypobaric chambers and onboard military transport aircraft. Hypobaric chamber flights were of three types:

1. Eight subjects were tested on high-altitude flights at 7,620 m (25,000 ft) with the same procedure as the rigid gas-permeable lens tests.
2. Ten subjects were tested in explosive rapid decompressions from 2,438.4 m (8,000 ft) to 7,620 m (25,000 ft) (Fig. 2).
3. Twelve subjects were tested during 4-h flights at 3,048 m (10,000 ft).

There were 34 subjects tested onboard transport aircraft flights with cabin pressures equivalent to 1,524 m (5,000 ft) to 2,438.4 m (8,000 ft) and ranging in duration from 3 to 10 h. Visual acuity measurements and slit-lamp examinations were performed before, during, and after the chamber and aircraft flights.

RESULTS

Rigid Gas-Permeable Lenses: All subjects developed bubbles at the edge of their lenses at altitudes greater than 6,096 m (20,000 ft). These bubbles disappeared rapidly after the subject blinked several times. Central subcontact lens bubble formation was detected in two subjects (Fig. 3). The bubbles were found in only one eye of each subject. One subject was wearing a silicone-PMMA polymer rigid lens and the other subject was wearing silicone rigid lenses with an aspheric base curve. In both cases, at 7,620 m (25,000 ft), the bubbles were noted as many small ones, located centrally, that dissipated upon descent to 6,096 m (20,000 ft). Neither subject was aware of their presence, and visual acuity, as measured on a Bausch and Lomb Visual Test Apparatus, was unaffected. No damage to the corneal epithelium was detected in either subject.

Soft Hydrophilic Lenses: Subcontact lens bubble formation was detected during the various hypobaric exposures, with an incidence of approximately 24% (a total of 22 of 92 eyes). In all cases, the bubbles were located only at

Fig. 3. Central subcontact lens bubbles beneath a rigid gas-permeable lens at an altitude of 7,620 m (25,000 ft).

the limbus (Fig. 4), none being detected over the central cornea. Bubbles were noted at altitudes as low as 1,828.8 m (6,000 ft) and, once formed, would increase in size and coalesce with increasing altitude. The bubbles did not disappear with blinking, but dissipated over a several-minute duration. There was no effect on vision or corneal epithelial integrity, nor were any of the subjects aware of their presence.

DISCUSSION

The quantity of a gas that can remain dissolved in a solution is directly proportional to its partial pressure and its solubility coefficient in a given medium (Henry's Law). Even if a solution is supersaturated with a gas such as nitrogen, bubbles will not form unless the pressure differential is extremely large (1). However, small bubble nuclei that already exist in solutions can expand as the pressure decreases (Boyle's Law); and, if trapped by an impermeable or semipermeable membrane, may grow large enough to be observed. Bubble nuclei may form in areas of negative hydrostatic pressures, such as those which may be produced from the contact lens tear pump.

The bubbles that formed in this study under the gas-permeable lenses, both rigid and soft types, dissipated rapidly, whereas bubbles under PMMA lenses remained for longer durations (3). Additionally, the absence of bubbles in tear films of eyes not covered by a contact lens indicates that subcontact lens bubble formation may be purely a barrier problem related to the lack of or insufficient gas permeability of the contact lens polymer. Therefore, the occurrence of subcontact lens bubble formation and their duration would predictably be related to the overall gas transmissibility of the contact lens.

Fig. 4. Limbal subcontact lens bubbles beneath a soft contact lens at an altitude of 7,620 m (25,000 ft).

The previous investigations of nongas-permeable lenses (PMMA) indicate that the use of these contact lenses by individuals in hypobaric environments may cause visual degradation as the result of subcontact lens bubbles (3). Although central bubble formation was observed with rigid gas-permeable lenses, no resultant visual changes were detected. However, the rigid gas-permeable lenses were tested only to 7,620 m (25,000 ft), whereas the PMMA lenses were tested to 12,192 m (40,000 ft). Whether the bubbles that formed under the rigid gas-permeable lenses in this study would grow and coalesce at higher altitudes, as happened with the PMMA lenses, and would result in degraded vision remains for further study. For soft (hydrophilic) lenses, bubbles were detected in 24% of the eyes, but were only located at the limbus and were without sequela to vision or corneal epithelial integrity.

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